The Water Budget and Its Use in Irrigation

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The purpose of irrigation is to counteract drought by making certain that the plants are not deprived of water at any time during their development. It is not possible to determine to what extent rainfall fails to supply the needs of plants for water without knowing their water requirements. Therefore the determination of the rates and the amounts of evaporation and transpiration from land surfaces under different types of cover in different parts of the country has been a research problem of major importance for a long time.

Scientists have tried various ways to determine the amount of water used by plants. One of the earliest attempts was to remove leaves or branches from a plant, let them dry for a brief time, and weigh them to see how much water they had lost. Another method is to place plants in sealed containers and measure the moisture that accumulates in the confined air. Experimenters have grown thousands of individual plants in pots, weighing them periodically to determine the evapotranspiration losses. These methods are highly artificial, and any generalizations from them sometimes have been greatly in error. In a German study, for example, transpiration from an oak woodland was computed as being more than eight times the total rainfall.

The only method so far developed that measures the evapotranspiration from a field or any other natural surface without disturbing the vegetation cover in any way is the so-called "vapor transfer" method. Water vapor, when it enters the atmosphere from the ground or from plants, is carried upward by the moving air in small eddies or bodies of air that are replaced by drier eddies from above.

We cannot see water vapor, but we can measure it in the air. We find that when evaporation is taking place the amount of moisture is greatest in the air near the ground and decreases with height above it. If we determine the rate at which the air near the ground is mixing with the air above it and at the same time measure the difference in water-vapor content at the two levels, we can determine both the rate and the amount of evapotranspiration. Furthermore, we can determine equally well the amount of water condensed as dew.

This method is not easy to understand or to use. It is hard to use because it requires physical measurements more precise than are usually made. Furthermore, the coefficient of turbulent transfer of air varies from time to time and from place to place. It even varies with height at a given time and place. Despite these difficulties, the method can be perfected and will answer many important questions for climatology and biology.

There are other ways of determining both water use and water need. Rainfall, water applied by irrigation, and water outflow are all measured in some irrigated areas. The fraction of water applied that does not run off is the evapotranspiration. In a few isolated places, mostly in the western United States, irrigation engineers have determined the evapotranspiration from plants growing in sunken tanks filled to ground level with soil in which water tables are maintained at different predetermined depths beneath the soil surface.

Increasing thought has been devoted since 1946 to the problem of measuring the water use of plants under always optimum conditions of soil moisture, and an instrument has been developed and standardized. It consists of a large soil tank so constructed that plants can be grown in it under essentially field conditions and can be provided with water as they need it. The tanks are 4 square meters in area and contain soil to a depth of approximately 70 centimeters. They have means for subirrigation from a supply tank designed so that actual amounts of water used can be accurately measured, or they can be irrigated by sprinkling from above. This latter method seems much more satisfactory in practice. When it rains, any excess water drains through the soil and is similarly measured. Thus every term in the hydrologic equation except evapotranspiration is measured. Evapotranspiration therefore can be determined as a difference. A number of these evapotranspirometers are in operation in widely scattered areas of the world, but many additional installations are needed if we are to understand the variation of evapotranspiration from one area to another.

From the various methods of determining evapotranspiration, imperfect and scattered though they may be, we get an idea of how much water is transpired and evaporated under different conditions. We find that the rate of evapotranspiration depends on five things: The climate, the supply of soil moisture, plant cover, the soil type and structure, and the land management. When the soil moisture is maintained at the optimum, land management and soil type or structure have little effect on the rate of evapotranspiration. Considerable evidence shows also that when the root zone of the soil is well supplied with water, the amount used by the vegetation depends more on the amount of solar energy received by the surface and the resultant temperature than on the kind of vegetation growing in the area. The water loss under optimum conditions of soil moisture, the potential evapotranspiration, thus appears to be determined principally by climatic conditions.

THREE POSSIBLE SOURCES of energy for evaporation or evapotranspiration are solar radiation, heat that reaches the evaporating surface from the air, and heat that is stored in the evaporating body. The latent heat of vaporization ranges from 574 cal/cc at 40° C. to 596 cal/cc at 0° C. If the heat needed for the evaporation of a small film of water came from the water itself, the water surface would be cooled well below the dewpoint. Thus, with no external source of energy, the surface temperature would quickly drop to the dewpoint of the air, and evaporation would cease. In an extensive body of deep water, evaporation could feed on the specific heat of the water for some time, but the process would cease long before much of the water had evaporated. Evaporation consequently can occur as a continuing process only while energy is being received from some outside source.

The sun is the original source of all energy that is involved in the transformation from liquid to water vapor. Not all of the energy received from the sun is used in evaporating water, however. Some of the incoming solar radiation is immediately reflected from the surface back to the sky. For a surface covered with vegetation, the reflected radiation may constitute about 25 percent of the total incoming. Also a certain percentage of the incoming radiation is radiated from the surface back to the sky; the amount depends on the temperature of the earth's surface and on the sky above. It is often between 10 and 15 percent of the incoming radiation.

After deducting the losses due to reflection and back radiation, the remainder (which is known as the net radiation) must be partitioned into three parts—one part heats the soil, one heats the air through contact with the soil surface, and one is utilized in evaporation.

In 1953, while participating in an Air Force field expedition to O'Neill, Nebr., the Laboratory of Climatology obtained an extensive series of micrometeorological measurements from which it is possible to compute the various components of the net radiation for a number of days. The computations show that when the soil is very moist more than 80 percent of the net radiation is used in evaporation. When the soil is dry, evaporation is greatly reduced, and most of the net radiation

Heat Used for Convection, Evaporation, and Storage in Soil, and Soil-Moisture Content on Different Days at O'Neill, Nebr., 1953

Date	Heat used for convection (C) (cal/cm²)	Heat stored in soil (S) (cal/cm²)	Heat used for evaporation (E) (cal/cm²)	Total C+S+E (cal/cm²)	$\frac{E}{C+S+E}$ (%)	Soil moisture in 0–18'' profile (inches)
Aug. 13, 14	56.3	29.7	377.2	463.2	81	1.65
18, 19	59.1	−4.8	287.8	342.1	84	1.40
22	98.4	19.0	216.2	333.6	65	1.20
25	181.9	41.5	131.8	355.2	37	1.05
31	242.3	28.3	44.5	315.1	14	.75
Sept. 3, 4	121.1	−47.5	136.5	210.1	65	1.20

is devoted to heating the air, with very little remaining for evaporation. Between those extremes, the proportion of the net radiation that is spent on evaporation varies in a manner that has not been determined fully.

In the United States, the heat budget method of determining evaporation, which was originally suggested by W. Schmidt in 1915, was recognized as physically sound but was considered impractical because of the difficulty in obtaining the many necessary observations. Certain simplifying assumptions made it possible to compute evaporation from a lake or other large free water surface. But no way was found to determine the evapotranspiration from a land surface, where its rate is dependent on the amount of water in the soil.

This difficulty has been overcome by the introduction of the concept of potential evapotranspiration. When the soil moisture falls below field capacity, if the percentage of the net radiation utilized in the vaporization of water is proportional to the moisture in the soil, it is easy to determine the evapotranspiration from areas with varying amounts of soil moisture. Except for the fact that heat from the soil and from the air are additional sources of energy for evapotranspiration, it would be possible to determine the potential evapotranspiration directly from the net radiation.

Different types of vegetation differ in their potential evapotranspiration because they absorb different amounts of solar radiation. More incoming solar radiation is reflected back to the sky and less remains for heating and for evaporation as the albedo of a surface increases. (Albedo is the ratio which the light reflected from an unpolished surface bears to the total light falling on it.)

Anders Ångström has given the albedos of a few different surfaces as follows: Grass, 0.26; oak woodland, 0.175; and pine forest, 0.14. We have found that many of the common garden vegetables have albedos similar to that of grass. Potential evapotranspiration, from the three types of vegetation listed, should be least from the grass-covered surface and greatest from the pine-forest.

Considerable work must still be done in determining the exact contribution of each of the three sources of energy for evaporation under different conditions of climate, soil structure, and moisture. Because of these unknown factors and because observations of net radiation are very few and cannot yet be computed directly, it is still necessary to refer to other climatic data in order to determine the distribution of potential evapotranspiration.

THE MOST RELIABLE measurements of evaporation and transpiration that can be related to climatic factors in an effort to obtain a valid and practical relationship are based on the monthly or seasonal data from irrigation and drainage projects and on daily observations from carefully operated evapotranspirometer tanks. It has been found that, when the adjustments are made for variations in day length, a close relation exists between mean temperature and potential evapotranspiration. Study of the available data has resulted in a formula that permits the computation of potential evapotranspiration for any place whose latitude is known and where temperature records are available. The formula is given in the preceding chapter.

Work is proceeding in several places toward the development of a new formula that is based on physical principles. In the meantime, the present empirical formula is being widely used in various studies of water balance.

Average annual potential evapotranspiration has been computed with this formula for some 3,500 Weather Bureau stations in the United States, and a map of the distribution of potential evapotranspiration has been prepared.

The average annual water need ranges from less than 18 inches in the high mountains of the West to more than 60 inches in three isolated areas in the deserts of Arizona and southern California. It is less than 21 inches along the Canadian border of the eastern United States and more than 48 inches in Florida and southern Texas.

The march of potential evapotranspiration follows a uniform pattern through the year in most of the United States. It is negligible in the winter months as far south as the Gulf Coastal Plain. It is only 2 inches a month in southern Florida. It rises in July to a maximum that ranges from 5 inches along the Canadian border to 7 inches on the gulf coast. In some mountain areas and along the Pacific coast, it does not reach 5 inches in any month.

The march of precipitation is highly variable from one region to another. In much of the United States more than half the rain falls in the growing season. In the Pacific Coast States the distribution is reversed; most of the rain falls in winter.

Since rainfall and evapotranspiration are due to different things, they are not often the same either in amount or in distribution through the year. In some places more rain falls month after month than the vegetation can use. The surplus moves through the ground and over it to form streams and rivers and flows back to the sea. In others, month after month, there is less water in the soil than the vegetation could use if it were available. There is no excess of rainfall and no runoff, except in places where the soil cannot absorb all the water as it falls. Consequently there are no permanent rivers and there is no drainage to the ocean. In still other areas the rainfall is deficient in one season and excessive in another, so that a period of drought is followed by one with runoff.

A FARMER who proposes to supply supplementary water to his crops must have some practical means of determining how much water to use and when it is needed. A common practice among farmers is to watch the plants for signs of moisture deficiency as a basis for supplying water. That is not satisfactory, because by the time the plants begin to show some signs of water need they are already suffering, and the yield has been reduced correspondingly.

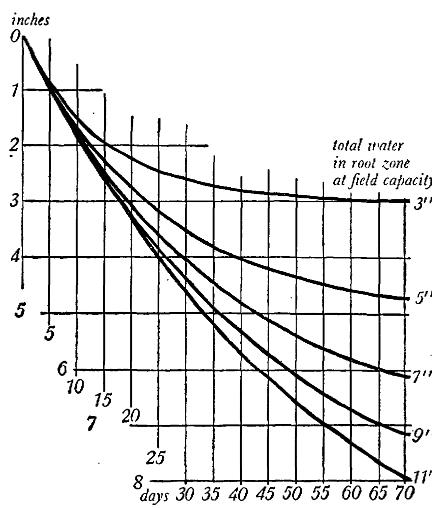
Instead of watching the crop for indications of drought, some investigators suggest watching the soil. One investigator has stated that the only known way to be sure that soil moisture is present in readily available form is by frequent examination of the subsoil by the use of a soil auger or similar tool. Several devices have been developed to be installed permanently in the soil to give a continuous indication of the amount of moisture remaining. Among these devices are elements made of gypsum, fiber glass, and nylon in which the electrical resistance varies with moisture. Many of these blocks have been used in some of the large irrigation enterprises to determine the time to apply water. Details about them are given on pages 362–371.

The climatological approach is different. The moisture in the soil is regarded as being a balance between what enters it as a result of precipitation and what leaves through evaporation and transpiration. Precipitation is easily measured by means of raingages, and good farmers regularly keep account of it. It is not easy to measure evapotranspiration, but the research we described provides a way to determine it. Consequently we can determine the daily moisture loss from the soil through evapotranspiration and can compare it with the daily rainfall. An irrigation schedule thus can be set up as a bookkeeping procedure. The moisture in the soil may be regarded as a bank account. Precipitation adds to the account; evapotranspiration withdraws from it. We merely need to keep track of the evapotranspiration and restore by irrigation whatever is not promptly returned by precipitation.

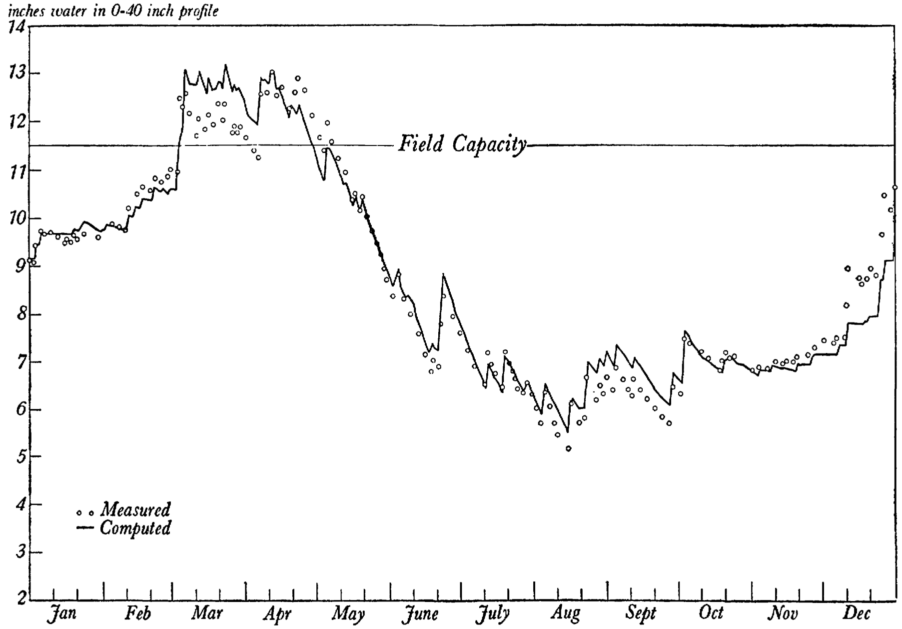
When the moisture content of the soil is at field capacity or above, any water that is added to it by precipitation is lost by downward percolation. This gravitational water is detained only briefly, the period depending on the permeability of the soil and the amount of the gravitational water. When the soil moisture is below field capacity, precipitation first brings the soil moisture storage up to that level. The amount of water that can be stored in the root zone of the soil depends on its depth and on the soil type and structure. With shallow-rooted crops on a sandy soil, only 1 to 2 inches of water can be stored for free use of the plants. With deep-rooted crops on a fine-textured soil, as much as 6 to 8 inches of water will be readily available. The amount of water that can be held as storage must be determined from a consideration of the soil and crop in each instance.

In computing the depth of water in a soil column, we must consider separately the gravitational water and the capillary water. At field capacity, the soil contains no surplus of gravitational water and no deficit of capillary water. Thus field capacity becomes an important point in the computation.

Evaporation from a moist soil begins immediately to lower the moisture content of the soil. As the soil dries, the rate of evapotranspiration diminishes. Evapotranspiration at first goes on at nearly the maximum rate from all soils, but by the time 1 inch of water has been removed the rates from different soils begin to differ. When one-half of the water is gone, the rate of evapotranspiration falls to one-half of the potential rate, and plants begin to suffer from drought. With a constant rate of potential evapotranspiration of 0.2 in/day, the half-rate would be reached after 7 days in coarse sand but not until after 37 days in fine-textured soil. Within 20 days the soil moisture in coarse sand would be reduced to a point where the evapotranspiration is only 25 percent of the potential rate. Long before that much water has been lost, the plants are suffering severely from lack of water, and growth is seriously retarded. In soil that can store 11 inches of water, this same degree of drought would be reached only after 75 days. Tables have been prepared for making the computations. They give the daily rates of soil moisture deple-



This sketch shows actual rate of soil moisture depletion from soils holding different amounts of water in the root zone, assuming a constant rate of potential evapotranspiration of .2 inch a day.



Soil moisture in 0–40'' profile on Watershed Y102, Coshocton, Ohio, 1944. Measured values obtained by Soil Conservation Service from soil samples and by use of weighing lysimeter. Computed values are from daily climatological data; the water budget method was used.

tion under varying rates of evapotranspiration for soils holding different amounts of water at field capacity.

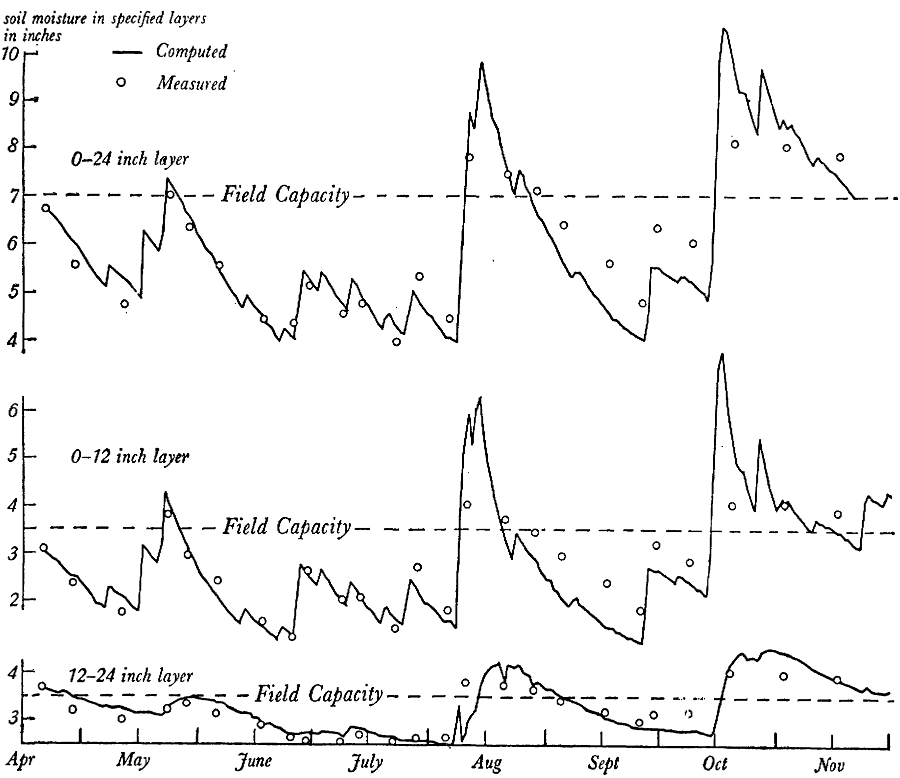
On the basis of the concepts we have outlined, the day-to-day variations in soil moisture have been worked out for several places in the United States. The results have been compared with actual soil moisture determinations. Considering the assumptions and approximations made in computing soil moisture on the one hand and the methods of soil sampling employed on the other, close agreement has been found between the measured and computed values of soil moisture.

In making the computations for other localities with different types of soil and for root zones of different depths, we must use the appropriate rate of soil moisture depletion determined for the particular amount of water held in the considered depth of soil at field capacity. Thus we can compute the trend of soil moisture in any type of soil and for a soil layer of any desired thickness. Furthermore, the water regimes of individual layers of the soil profile can be determined separately from the climatic data.

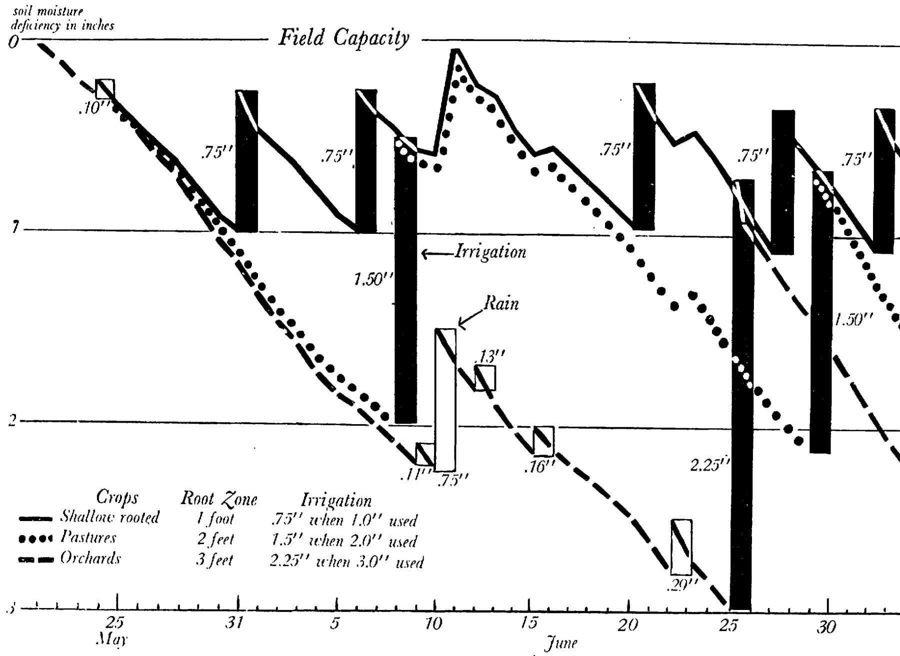
Computations for a number of places and for different years support the conclusion that soil moisture can be determined with all needed precision from climatological data. It is apparent from the agreement found between measured and computed values that the climatological approach will permit the accurate determination of the movement of water through soils and the amount of storage in any selected layer in the soil. It is still necessary, however, to make certain assumptions in order to obtain the computed values. Further work should make it possible to refine the method and to base it on sound physical principles.

An irrigation schedule is a natural outgrowth of this method of computing soil moisture. One can set up limits below which the soil moisture will not be allowed to fall for the particular crop and depth of root zone in question. Then, by keeping daily account of how much water has been lost from the soil, we could know exactly when the predetermined level of soil moisture depletion is reached and to know just how much to irrigate to bring the moisture level back to a safe value. Shallow-rooted crops will have to be irrigated more frequently but with smaller amounts of water than will deeper-rooted pastures or orchards. If irrigation is scheduled by keeping continuous account of the soil moisture, no great moisture deficiency can develop in the soil to limit growth and there will be no overirrigation to damage both soil and crop and to result in a wasteful misuse of water.

Sometimes it is not necessary or desirable to make detailed daily computations of deficiency of soil moisture. For instance: A basic problem in agriculture is to determine the intensity and frequency of drought as a step in the evaluation of the economic feasibility of irrigation. To make a quantitative determination of drought intensity, it is necessary to have records of soil moisture deficiency, while to determine drought frequency, soil moisture records for a long series of years are needed. In this case the precision that can be gained by using daily



Soil moisture in specified layers of soil profile, College Park, Md., 1942. Measured values obtained by Soil Conservation Service from soil samples. The values were computed from daily climatological data; the water budget method was used.



This sketch shows the irrigation schedule for three different types of crops, in Seabrook, N. J., 1954. Soil holds 3 inches of water at field capacity per foot depth of soil. Rain on May 21 brought soil up to field capacity so that computations of deficiency start from 0 on that day.

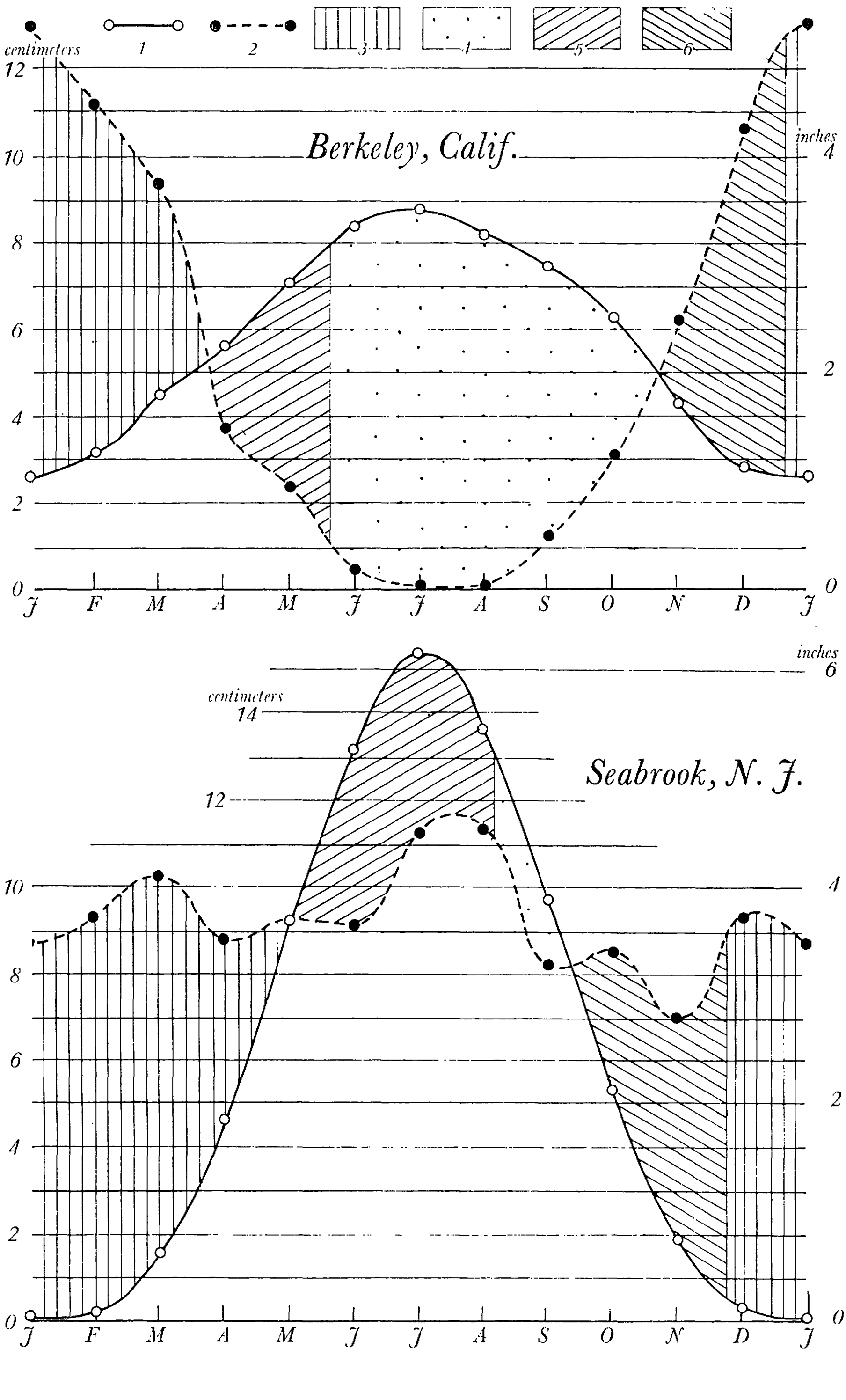
climatological values for computing soil moisture deficiency is not warranted. It would be more satisfactory to use monthly means of temperature and precipitation and to determine moisture deficiency with perhaps less accuracy but for more years of record and for a greater number of stations than would otherwise be possible.

In using monthly instead of daily values of climatic factors, certain of the procedures employed in the daily computations can be generalized. For example, although it is recognized that the amount of water in the root zone available to plants will vary with soil structure from about 1 inch on shallow soils to about 6 to 8 inches on deep, well-aerated, silt loam, in normal agricultural soils the total amount of water available to plants is far less variable than conventional studies of soil moisture would indicate. A satisfactory average has been found to be 4 inches.

Gravitational water can be easily handled in the monthly computations, since it is possible to consider surface runoff and the percolation of gravitational water as one quantity, runoff. It is not necessary to employ any daily factor for the detention of gravitational water in the profile but merely a general monthly detention factor for all runoff, a factor that varies with the size of the watersheds and is about 50 percent for large watersheds.

Using these more general assumptions, we can compare the monthly march of precipitation and potential evapotranspiration at different places.

At Seabrook, N. J., the potential evapotranspiration is negligibly small in winter, but in early spring it begins a rapid rise, which reaches the high point of the year of more than 6 inches in July. It falls rapidly in autumn. The corresponding precipitation is far more uniformly distributed throughout the



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year, being very close to 3.5 inches in 9 of the 12 months. The rainiest months are July and August, each of which receives about 4.5 inches; November, the driest month, has only 2.75 inches.

In this example, rainfall and water need do not coincide. There is too much rain in winter and too little in summer. Thus at the time of maximum rainfall in July and August there is a water deficiency, but in November, when rainfall drops to the lowest value of the year, there is a water surplus. Water need falls below precipitation in early autumn. For a while the surplus rainfall replaces soil moisture that had been used up previously. From then on, the surplus water raises ground water levels and produces surface and subsurface runoff. Both transpiration and evaporation increase rapidly in spring, and soon water need surpasses precipitation. When the soil moisture is at field capacity, actual and potential evapotranspiration are the same and all precipitation in excess of the potential evapotranspiration is realized as water surplus. When precipitation does not equal potential evapotranspiration, the difference is made up in part from soil moisture storage; but as the soil becomes drier the part not made up is larger. This is the water deficit, the amount by which actual and potential evapotranspiration differ.

BOTH WATER SURPLUS and water deficit can be derived from the comparison of the monthly precipitation with the monthly potential evapotranspiration. The water surplus occurs in winter in Seabrook and amounts to about 15 inches, and the water deficit occurs in summer and amounts to about 1 inch. Through the course of the year there is a net water surplus amounting to 14 inches. This system of monthly water bookkeeping makes it possible also to determine the water that must be accounted for as the soil moisture storage.

In Berkeley, Calif., in a different climatic zone, nearly all the rainfall comes in winter and almost none in summer. Here the winter water surplus is 4 inches and the summer water deficit of 7 inches therefore are both comparatively large.

Both rainfall and potential evapotranspiration vary from one year to another. Thus conclusions based on longtime averages tell only a partial story. Even a very rainy place may occasionally experience drought. The length and severity of summer drought in Seabrook and Berkeley vary greatly from year to year.

TO DETERMINE how severe drought may be in a place, we must compare water need with water supply in individual years. In that way we can determine how often water deficiencies of various amounts take place. As an example we may consider selected moisture data obtained during the 25-year period, 1920–44, at four stations in agricultural areas of the United States: Hays, Kans.; Charles City, Iowa; Wooster, Ohio; and Auburn, Ala.

In Hays, the least rainy station, the average rainfall is about 22 inches. In Auburn, the rainiest, it is about 50 inches. The average rainfall in Hays is about 10 inches less than the need; in Auburn it is 10 inches greater. In Auburn, however, much of the rainfall comes in winter, when it is not needed. It becomes surplus water and flows away. In the summer, however, water deficiency is large. Water deficiency in Hays also is large, ranging from nearly 20 inches to about 2 inches. In Hays there is not enough rainfall; in Auburn there is more than enough, but it is badly distributed through the year.

In both Charles City and Wooster, with a better distribution of rainfall

Average march of potential evapotranspiration (1) and precipitation (2) through the year at Berkeley, Calif., and Seabrook, N. J. Diagrams also show other factors of the moisture balance: Water surplus (3); water deficit (4); soil water utilization (5); and soil water recharge (6).

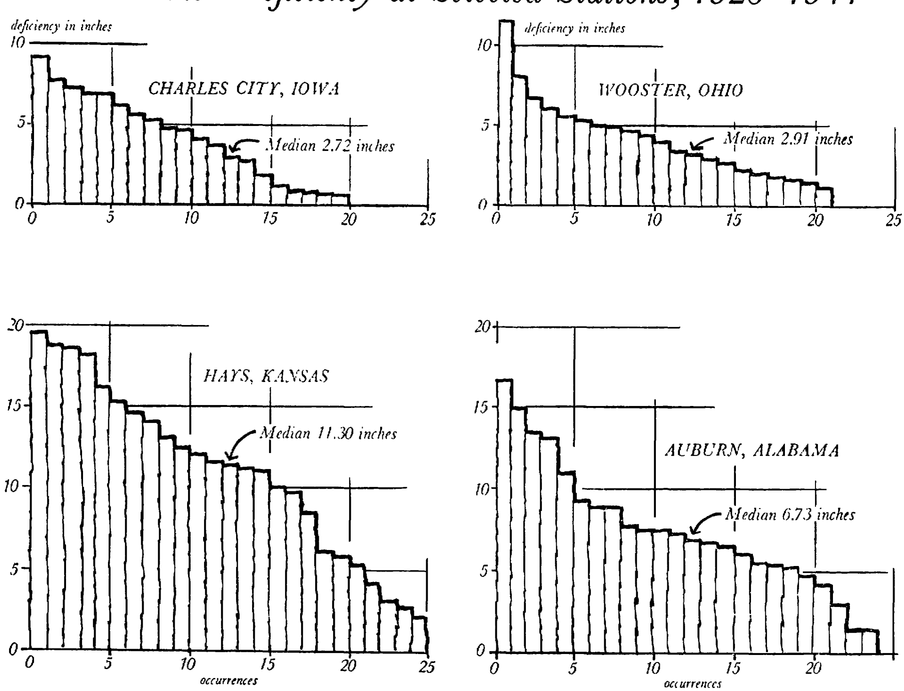
Comparative Moisture Data at Selected Stations in the United States—Median Values of the 25-year Period 1920–1944

Station	Precipitation (inches)	Potential evapotranspiration (inches)	Actual evapotranspiration (inches)	Water surplus (inches)	Water deficiency (inches)
Hays, Kans	22.13	31.26	21.02	0.00	11.30
Charles City, Iowa	30.94	25.91	23.19	8.90	2.72
Wooster, Ohio	35.63	26.46	23.82	11.26	2.91
Auburn, Ala	49.84	39.45	33.07	18.43	6.73

through the year, the water deficiencies are smaller, being less than 1 inch and 3 inches, respectively, in half of the years of record. Drought intensity and frequency are a little smaller in Charles City than in Wooster. There is also a lower water surplus in Charles City—8.90 inches, compared with 11.26 inches. Thus, of the four stations, Charles City most nearly approaches the ideal climate for agriculture, for its water supply most nearly coincides with water need.

MANY STATISTICAL STUDIES of drought have been made, but almost without exception they are mere tabulations of days receiving less than a specified amount of rain. For example, in a probability analysis of drought in the United States, published in 1942, a drought period was defined as one in which not more than 0.10 inch of precipitation occurred in any consecutive 48 hours. In 1946 the drought periods of six Georgia stations were tabulated, drought being defined as "a period of

Annual Water Deficiency at Selected Stations, 1920–1944



14 days or more in which there is not one-quarter of an inch of rainfall in any one 24-hour period." A suggestion was made in 1954 that punched cards of the Weather Bureau be used to tabulate the number of days without rain during the growing seasons at various places in the last 20 years. The tabulations "would yield the basis for saying that in July, 3 years out of 5 will get one dry spell which will last 18 or more days." Such tabulations, it was thought, would enable agricultural engineers and others to tell farmers whether they should invest in irrigation equipment.

Such tabulations of the number of days without rain actually do not give information about drought: We cannot define drought only as a shortage of rainfall, because such a definition would fail to take into account the amount of water needed. Furthermore, the effect of a shortage of rainfall depends on whether the soil is moist or dry at the beginning of the period.

H. L. Shantz explained that drought in its proper sense is related to soil moisture and that it begins when the available soil moisture is diminished so that the vegetation can no longer absorb water from the soil rapidly enough to replace that lost to the air by transpiration. Drought does not begin when rain ceases but rather only when plant roots can no longer obtain moisture in needed amounts.

Differences in average yields in different localities are proportional to differences in drought incidence. The farmers of the East and Southeast get low returns from their work on the land partly because of high drought incidence resulting from the lack of coincidence between rainfall and water need. During much of the growing season, the soil does not contain enough moisture, and in the nongrowing season a large water surplus impoverishes the soil by leaching.

To farmers everywhere drought is a serious matter. Drought is hard to measure because we are not yet able to determine the water needs of plants very accurately. We do not know when to expect droughts or how intense they may be. Therefore we cannot be sure which moisture-conservation measures may be best at a given time and place. Droughts deserve study. Not until we have conquered drought by scientific irrigation will we achieve the maximum production from the soil.

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Soil Moisture in Relation to Plant Growth

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Growing plants transpire enormous quantities of water which they take from the soil. One cornfield in Iowa transpires enough water during a season to cover the field to a depth of 12 or 16 inches. The production of 1 ton of dry alfalfa hay on the Great Plains may involve the transpiration of 700 tons of water—more or less, depending on the evaporating power of the atmosphere. At a temperature of 75° F. and a relative humidity of 50 percent, a tensional force of approximately 1,000 atmospheres would have to be applied to water to stop evaporation.

Plants lose water continuously. The lowest loss is at night and the highest at midday. But often the soil water is not replenished by rain or irrigation over periods of weeks or months. Hence the soil acts as a moisture reservoir for the plants.

To a Colorado wheat grower, who may harvest 50 bushels an acre or nothing, according to the status of the moisture reservoir in his soil in a given season, it would be difficult to overemphasize the importance of soil moisture in plant growth.

The capacity of the soil moisture reservoir is limited by the field capacity (upper limit) and the permanent wilting percentage (lower limit) of the soil in the effective root zone of a crop. Field capacity is the moisture percentage of a soil, expressed on dry-weight basis, in the field 2 or 3 days after a thorough wetting of the soil profile by rain or irrigation water. Permanent wilting percentage is the moisture percentage of soil at which plants wilt and fail to recover turgidity. It is usually determined by growing dwarf sunflower plants in small containers of the soil under examination. The moisture held by the soil against a displacing